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Ground Water Quality

EPIC Tile Flow and Nitrate Loss Predictions for Three Minnesota Cropping Systems

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ABSTRACT

Subsurface tile drains are a key source of nitrate N (NO_3–N) losses to streams in parts of the north central USA. In this study, the Erosion Productivity Impact Calculator (EPIC) model was evaluated by comparing measured vs. predicted tile flow, tile NO_3–N loss, soil profile residual NO_3–N, crop N uptake, and yield, using 4 yr of data collected at a site near Lamberton, MN, for three crop rotations: continuous corn (*Zea mays* L.) or CC, corn–soybean [*Glycine max* (L.) Merr.] or CS, and continuous alfalfa (*Medicago sativa* L.) or CA. Initially, EPIC was run using standard Soil Conservation Service (SCS) runoff curve numbers (CN2) for CC and CS; monthly variations were accurately tracked for tile flow (r^2 = 0.86 and 0.90) and NO_3–N loss (r^2 = 0.69 and 0.52). However, average annual CC and CS tile flows were underpredicted by −32 and −34%, and corresponding annual NO_3–N losses were underpredicted by −11 and −52%. Predicted average annual tile flows and NO_3–N losses generally improved following calibration of the CN2; tile flow underpredictions were −9 and −12%, whereas NO_3–N losses were 0.6 and −54%. Adjusting a N parameter further improved predicted CS NO_3–N losses. Predicted monthly tile flows and NO_3–N losses for the CA simulation compared poorly with observed values (r^2 values of 0.27 and 0.19); the annual drainage volumes and N losses were of similar magnitude to those measured. Overall, EPIC replicated the relative impacts of the three cropping systems on N fate.

Pressure is growing worldwide to adopt agricultural cropping and management systems that ensure a safe food supply but avoid negative environmental externalities. As a result of this paradigm shift, agricultural policy makers and other decision makers are faced with an increasing need for timely information that can address these concerns. Research results from long-term field and monitoring studies, and applications of simulation models, are both playing key roles in supporting this need. An important contribution of simulation modeling is the ability to evaluate a variety of agricultural policy and management scenarios for many combinations of soils, landscapes, climates, and crops. This is especially useful in the context of integrated modeling systems, which can provide both economic and environmental indicators in response to potential changes in agricultural policies.

One tool that has been widely used for agricultural policy analyses is the Erosion Productivity Impact Calculator (EPIC) model (Williams, 1990; Williams, 1995) which consists of the following nine components: weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and crop budgets (costs and returns). EPIC was originally developed to assess the long-term impacts of erosion upon soil productivity. However, more recent versions of EPIC have also been used to estimate nutrient losses from fertilizer and manure applications (Edwards et al., 1994; Phillips et al., 1993), climate change impacts on crop yield and soil erosion (Favis-Mortlock et al., 1991; Brown and Rosenberg, 1999), edge-of-field leaching and runoff losses from simulated pesticide applications (Williams et al., 1992), and soil C sequestration as a function

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Abbreviations: EPIC, Erosion Productivity Impact Calculator; RAPS, Resource and Agricultural Policy System; CC, continuous corn; CS, corn–soybean; CA, continuous alfalfa; SCS, Soil Conservation Service; CN2, curve number; CRP, Conservation Reserve Program; EF, modeling efficiency.

of cropping and management systems (Lee and Phillips, 1993).

EPIC has been adopted within the Resources and Agricultural Policy System (RAPS), an integrated modeling system designed to evaluate the economic and environmental impacts of agricultural policies for the north central USA (Babcock et al., 1997; Wu and Babcock, 1999). The primary use of EPIC within RAPS is to provide N loss, soil erosion, and crop production indicators in response to variations in tillage treatment and crop rotation. Testing and validation of EPIC using measured data obtained at specific sites is a key component of applying EPIC within RAPS; previous validation results at a site in southwest Iowa are described by Chung et al. (1999). The goal of this testing is to improve the accuracy of the environmental indicators estimated by the model for as many combinations of cropping and management systems, soil, climate, and landscape conditions as possible that exist within the RAPS study region (Gassman et al., 1998).

The objective of this study is to evaluate the performance and reliability of EPIC version 5300 in predicting both long-term (annual and annual mean) and short-term (monthly) subsurface drain flow (tile flow) and nitrate N (NO_3–N) loss in tile flow with measured data. Long-term results of predicting residual NO_3–N in the soil profile, crop N uptake, and crop yield are also evaluated.

SITE DESCRIPTION AND INPUT DATA

Field Site

Measured data were obtained from a field study conducted at the University of Minnesota Southwest Experiment Station at Lamberton, MN. The study was performed from 1988 through 1993 to determine the effect of four conventionally tilled cropping systems on above-ground biomass yield and N uptake, water content and residual NO_3–N in the soil profile, and NO_3–N loss through tile drainage water (Randall et al., 1997). Four cropping systems were established in the spring of 1988 after secondary tillage: continuous corn, soybean–corn, continuous alfalfa, and alfalfa–grass mixtures established on Conservation Reserve Program (CRP) land. Each cropping system was replicated three times in a randomized, complete-block design. In this study, EPIC was tested against measured data averaged across three plots each during 1990–1993 for continuous corn (CC), corn–soybean (CS), and continuous alfalfa (CA).

Subsurface tile drainage systems (perforated, plastic, 10-cm tubing) with separate drain outlets were installed in 1972 below 15 individual 13.7 by 15.3 m plots. Tile lines were spaced to simulate 28-m spacing and placed 1.2 m deep (Randall et al., 1997). Individual plots were hydrologically isolated to a depth of 1.8 m by trenching and installation of a 12-mil thick plastic sheet. Measurements of tile flow were recorded for the experiments; no other water balance information was collected.

Soil Inputs

The soil at the experiment site is a moderately well-drained Nicollet clay loam (fine-loamy, mixed, mesic Aquic Haplustoll) that is classified as a hydrologic group B soil. The exact slope has not been measured at the site; an average slope of 1.5% was assumed for each simulation. Up to 20 physical and chemical soil properties for each soil layer can be input into EPIC; required values include layer depth, bulk density, wilting point, field capacity, percentage sand, percentage silt, pH, and percentage organic C. Soil layer inputs for the Lamberton site were based on measurements of soil samples collected at the research site (L. Klossner, personal communication, 1998, Univ. of Minnesota Southern Res. and Outreach Stn., Waseca, MN). A soil profile depth of 1.2 m was used to facilitate comparisons between predicted outputs and tile measurements.

Weather Inputs

Daily precipitation, and maximum and minimum air temperature, used for the simulations were measured at a site 700 m from the experimental plots. Monthly growing season precipitation summaries for the study period are given in Randall et al. (1997). The other daily weather data were generated within EPIC using monthly weather statistics for the Tracy Power Plant, which is the nearest Minnesota climatic station available in the EPIC weather generator database. These monthly weather statistics are part of a weather generator database originally developed by Nicks and Lane (1989) for the entire USA. The Hargreaves method (Hargreaves and Samani, 1985) was used to estimate the potential evaporation, as described in Williams (1995).

Management Inputs

Planting, harvesting, and other operation dates and fertilizer amounts entered in the model were based on those reported by Randall et al. (1997). Urea was broadcast-applied for corn each spring and incorporated within 24 h by cultivation. No N was applied to the CA or to soybean within the CS cropping system. Nitrogen rates applied to corn within CC and CS were determined as a function of the previous crop (corn or soybean), soil NO_3 concentrations, and a yield goal of 8.8 Mg ha^{-1}.

Initial Condition Assumptions

Data on initial soil NO_3–N concentrations (mg kg^{-1}) for 1990 were estimated using the residual NO_3–N amounts (kg ha^{-1}) in the soil profile up to a 1.2-m depth that were measured in October of 1989 and in April of 1990. The estimated values for initial soil NO_3–N concentrations were 5, 3, and 1 mg kg^{-1} for CC, CS, and CA. The initial soil water content, which is defined in EPIC as the soil water content normalized by the field capacity of the soil (SW/FC), was assumed to be 0.3 m m^{-1} for all three cropping systems because precipitation levels in the previous 2 yr (1988 and 1989) were <500 mm, resulting in soil profiles near the wilting point.

SIMULATION METHODOLOGY

The EPIC runoff model simulates surface runoff volumes and peak runoff rates in response to daily precipitation inputs. A modified version of the Soil Conservation Service (SCS) curve number method (Mockus, 1969) is used to partition precipitation between surface runoff volume and infiltration. The original SCS method antecedent moisture condition two runoff curve numbers (CN2) were derived on the basis of soil hydrologic group, land use, and management, but with no consideration of land slope. In EPIC, these CN2 values are adjusted as a function of slope, based on the assumption that the original CN2 values represent a 5% slope. Additional daily adjustments of the CN2 values are also made depending on the soil water content and distribution, and whether the soil is frozen (Williams, 1995).

Two different curve number scenarios were used to evaluate EPIC's ability to replicate the measured data for the CC and CS systems: (i) using the standard table values of CN2 (Case I) and (ii) adjusting the CN2 values at planting with a calibration process (Case II). The selection of the Case II CN2 value is discussed in the Results and Discussion section. For Case I, a curve number value with antecedent moisture condition 2 (CN2) of 78 was chosen for CC and CS, reflecting row crops planted in straight rows and good hydrologic conditions under soil group B (Mockus, 1969). For CA, the standard CN2 value given by Mockus (1969) is 72, reflecting a close seeded legume grown in straight rows and good hydrologic conditions for soil group B. However, a CN2 of 75 was determined to be the best choice for CA following calibration of the EPIC water balance components. Only one set of simulations was performed for CA, which is presented with the Case I CC and CS results.

Nitrogen Transport and Transformations

Nitrogen transport and transformation processes simulated in EPIC include NO_3–N in surface runoff, organic N transport by sediment, NO_3–N leaching, upward NO_3–N movement by soil water evaporation, denitrification, immobilization, mineralization, crop uptake, volatilization of NH_3, and fixation (Williams, 1995). Leguminous N_2 fixation was simulated for soybean and alfalfa; all other N processes were simulated for all three cropping systems. Fixation is simulated in EPIC by accounting for the effects of early nodule development, nodule senescence late in the growth cycle, soil water in the top 30 cm, and soil mineral N in the root zone (Williams, 1995; Bouniols et al., 1991).

The impact of these environmental factors upon fixation can be adjusted in EPIC with an empirical parameter denoted as parm7, which ranges in value from 0 to 1.0. Setting parm7 to 1.0 assumes that the effect of the environmental factors on the simulated fixation process will be fully accounted for. A parm7 value of 1.0 is recommended in the EPIC user's manual (Mitchell et al., 1996) for soybean. However, limited research has been performed regarding the best choice of this parameter for soybean under varying climatic and soil conditions (J.R. Williams, personal communication, 2000, Texas Agric. Exp. Stn., Blacklands Res. Lab., Temple, TX). Thus, a sensitivity analysis was conducted for this study in which the effects of two different parm7 values (1.0 and 0.3) were compared for soybean within the CS system. These two values provide a contrasting range of the effect of the different environmental factors on the fixation process. A parm7 value of 0.25 was used for alfalfa because perennial legumes are not very sensitive to the above-mentioned environmental factors.

Model Output Comparisons with Tile Measurements

Applications of EPIC for simulating tile drainage dynamics have been very limited. This is likely due in part to the simplistic way in which tile drainage can be simulated in the model, which is performed as a function of lateral subsurface flow and the time required for the drainage system to reduce plant stress (Williams, 1995). In a previous application of the EPIC5300 tile component, measured tile flow and NO_3–N loss were greatly underpredicted for a site in northeastern Iowa (S.E.Chung and R. Gu, unpublished report, 1996, Dep. of Civil Eng., Iowa State Univ.). Sabbagh et al. (1991) incorporated components of the DRAINMOD model (Skaggs, 1982) into a modified version of EPIC called EPIC-WT to provide a more rigorous methodology for simulating drainage flow. However, this approach is more complex than necessary for many applications and is not used in standard versions of EPIC.

For this study, it was assumed that the leached amounts predicted by EPIC at 1.2 m would be equivalent to the measurements at the tile line outlets for the monthly and annual comparisons. This is a reasonable assumption for the monthly and annual comparisons because the experimental plots (0.02 ha) and the tile line spacings (28.5 m) are small enough to carry the flow that enters the tile lines to the tile line outlets within several days. This assumption does ignore the possibility of water and nitrate losses that leach below the tile line depth, but these losses are likely minor at the Lamberton site. For the remaining discussion, the simulated leached water and NO_3–N at the tile depth are referred to as the simulated or predicted tile flow and tile NO_3-N loss.

Model Evaluation Methods

Both statistics and graphical displays are used to compare the EPIC predictions with observed values to evaluate the performance of the model. The statistics used for the tile flow and tile NO_3–N loss comparisons are percent error (% error), paired *t*-test, modeling efficiency (EF), and *r*-square (r^2); only the % error was used to evaluate the predicted soil residual NO_3–N levels, crop N uptake, and crop yield. The % error was mainly used to assess the error associated with the long-term (annual mean) performance of EPIC. The paired *t*-test, performed between the observed and simulated monthly values, was designed such that acceptance of the null hypothesis indicated that the EPIC-predicted mean value was statistically the same as the observed one. A significance level of $\alpha = 0.05$ (95% confidence level) was used for this study.

The EF, defined by Loague and Green (1991), describes the proportion of the variance of the observed values over time that are accounted for by the EPIC model, where the variance is relative to the mean value of the observed data (Nash and Sutcliffe, 1970; Martin et al., 1993). The EF can vary from 1 to negative infinity; an EF value of 1 indicates that the model predictions are exactly the same as the observed values. If $EF \leq 0$, it means that the observed mean value is as good an overall predictor as the model (or a better predictor of observed values than the model).

Explicit standards for evaluating model performance with statistics such as the EF and r^2 are not well established, because the judgment of model results is highly dependent on the purpose of the model application. For this study, the target criteria used by Chung et al. (1999) were used to judge if the model results were satisfactory; i.e., % error $< 20\%$, $EF > 0.3$, $r^2 > 0.5$, and $P > 0.025$.

RESULTS AND DISCUSSION

Case I: Tile Flow

Annual tile flow predictions generally reflected observed values, with greater flow predicted under row crops relative to alfalfa (Table 1). However, the simulated CC and CS annual average tile flows were underpredicted by −32 and −34%, exceeding the criteria of 20%. The predicted CA average annual tile flow was also underpredicted, but the % error of −14% was much closer to the observed value. The *P* values determined for CC, CS, and CA were 0.092, 0.068, and 0.704, indicating that the predicted mean values of the monthly tile flows were not statistically different from the averages

Table 1. Observed and simulated (Case I) annual subsurface tile flows for three cropping systems at Lamberton, MN.

		Tile flow					
		CC†		CS†		CA†	
Year	Rainfall	Observed	Simulated	Observed	Simulated	Observed	Simulated
	mm						
1990	623	20	37	19	27	0	17
1991	812	179	119	220	166	40	91
1992	766	132	96	124	72	55	31
1993	1028	443	275	480	293	323	221
Mean (% error‡)	807	193	132 (−32)	211	139 (−34)	105	90 (−14)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990); CA = continuous alfalfa.
‡ Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

of the monthly measured tile flows for each cropping system.

EPIC accurately tracked the CC and CS monthly tile flows (Fig. 1), with resulting r^2 and EF values of 0.86 and 0.71 for CC and 0.91 and 0.73 for CS. Monthly predictions for CA were much weaker, resulting in a value of 0.27 for both the r^2 and EF. Small amounts of tile flow occurred in 1990 for each cropping system, a year of normal precipitation, which was predicted well by the model using the initial soil water content of 0.3 (Fig. 1). However, the model consistently underpredicted the peak tile flows that occurred during the later spring and summer months in 1991 for CC and CS, and in 1993 for all three cropping systems. In particular, the predicted peak tile flows were half of the observed values for all cropping systems in 1993 when precipitation was 60% greater than normal.

One possible explanation of the tile flow underpredictions is that EPIC did not accurately capture the effect of the relatively flat slope at the Lamberton site, resulting in an overprediction of surface runoff and underprediction of leached water. Another potential source of error is the lack of a preferential flow component in EPIC. Preferential flow can occur through macropores after ponding during heavy storm events, resulting in quick movement of flow and nutrients from the soil surface to the bottom of the root zone (Singh and Kanwar, 1995). Although this phenomena is usually most pronounced in no-till soils, it can also occur in conventionally tilled soils (Singh and Kanwar, 1991; McCoy et al., 1994).

Case I: Nitrate Nitrogen Loss via Tile Flow

The model performance varied greatly in predicting annual NO_3–N tile losses from the different simulated crop management systems (Table 2). The annual average NO_3–N loss predicted for CC was 11% below the corresponding measured average. Annual mean simulated CS NO_3–N losses were −52% (parm7 = 1.0) and −41% (parm7 = 0.3) below the observed average annual value; both results exceeded the % error criteria of 20%. For CA, the predicted average annual NO_3–N loss was 100% greater than the measured mean. The P values generated from the t-test mirrored the % error results, with acceptance of the null hypothesis resulting for CC (P = 0.427) and rejection for CS (P = 0.24 for both parm7 simulations) and CA (P = 0.02). Overall, EPIC accurately reflected the reduced NO_3–N losses that occurred for CA relative to CC and CS.

Time-series comparisons between observed and simulated monthly values of the tile NO_3–N losses are shown

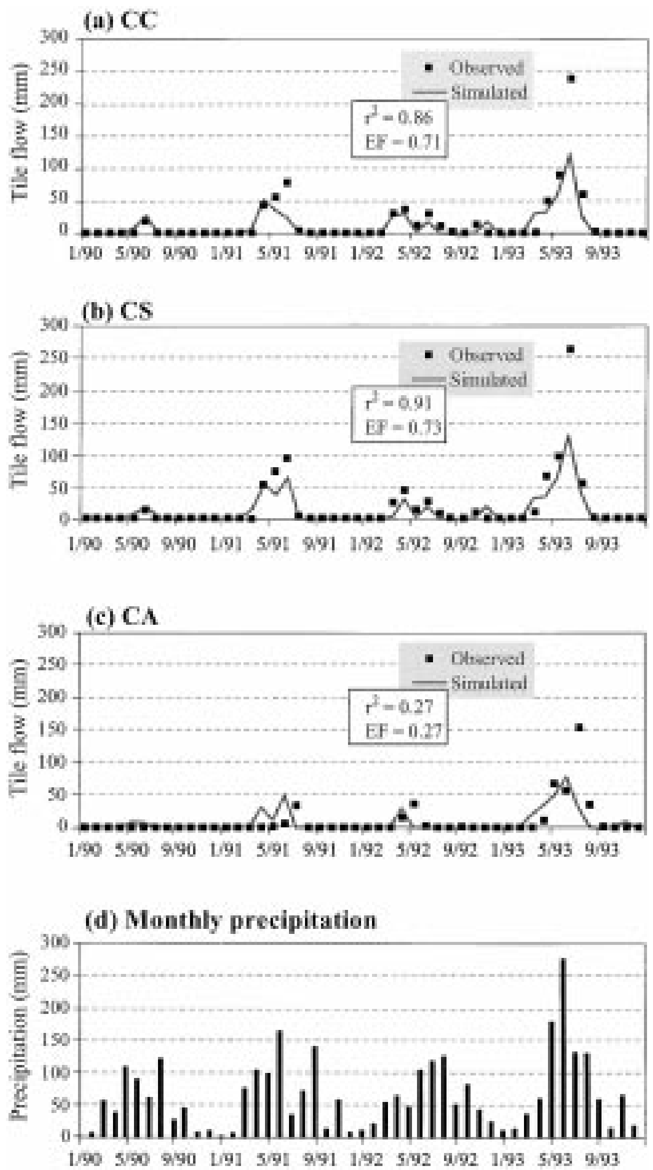

Fig. 1. Observed and Case I simulated monthly tile flows during 1990–1993 at Lamberton, MN, for (*a*) continuous corn (CC), (*b*) corn–soybean (CS), and (*c*) continuous alfalfa (CA); and (*d*) monthly precipitation.

Table 2. Observed and simulated (Case I) annual NO_3–N loss for three cropping systems at Lamberton, MN.

	NO_3–N loss						
	CC†		CS†			CA†	
Year	Observed	Simulated	Observed	Simulated‡	Simulated§	Observed	Simulated
	kg ha^{-1}						
1990	0	19	0	12	12	0	4
1991	70	55	81	62	62	1	3
1992	50	37	32	2	15	2	3
1993	84	71	67	10	17	4	4
Mean (% error¶)	51	46 (−11)	45	22 (−52)	27 (−41)	2	4 (100)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990); CA = continuous alfalfa.
‡ Simulated results with parm7 = 1.0.
§ Simulated results with parm7 = 0.3.
¶ % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

in Fig. 2. EPIC consistently underpredicted the amount of NO_3–N loss that occurred during the peak time periods under CC and CS, due in part to the underpredicted tile flows. Monthly NO_3–N loss trends were most accurately simulated for CC, resulting in r^2 and EF values of 0.69 and 0.68. The simulated CS monthly time series yielded relatively weak r^2 and EF values of 0.52 and 0.43 when parm7 was set to 1.0. Setting parm7 to 0.3 resulted in improved r^2 and EF values of 0.62 and 0.54. The simulated monthly tile NO_3–N losses were not impacted at all in 1990 and 1991 when parm7 was adjusted from 1.0 to 0.3 (Fig. 2). However, definite improvement resulted during the spring and summer of 1992 (Fig. 2), during which essentially no NO_3–N losses were simulated when parm7 was set to 1.0. Some improvement in the predicted NO_3–N losses also occurred in 1993 with parm7 set at 0.3 (Fig. 2). With the lower parm7 value, the N_2 fixation process was less sensitive to environmental conditions such as soil NO_3–N amount, water content, and crop growth stage, which resulted in greater amounts of leachable residual NO_3–N in the soil profile in October of 1991 and April of 1992.

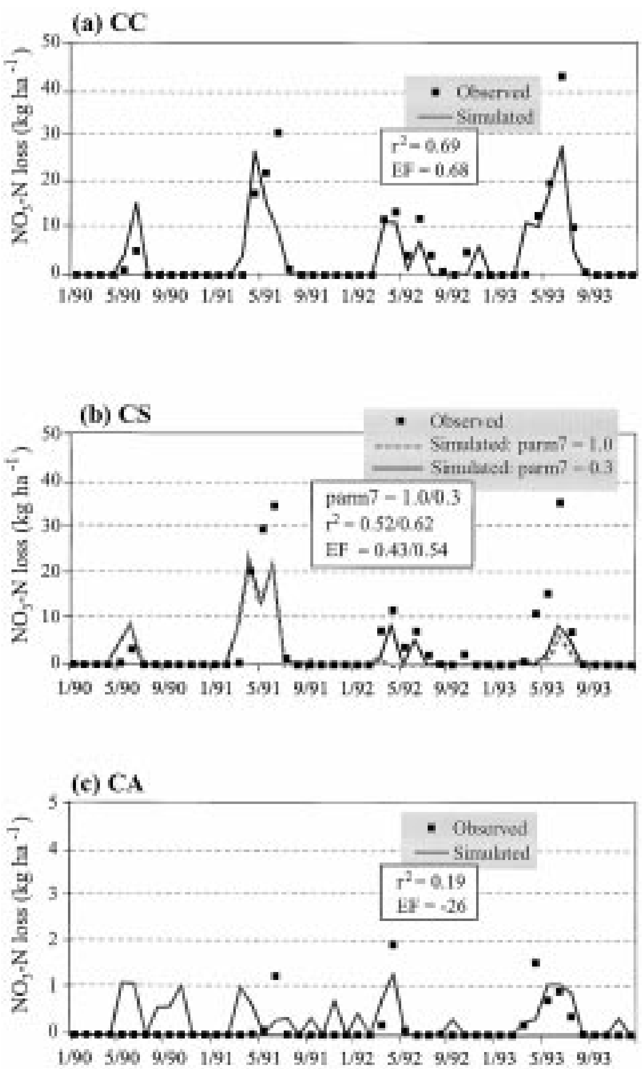

Fig. 2. Observed and Case I simulated monthly NO_3–N losses during 1990–1993 at Lamberton, MN, for (*a*) continuous corn (CC), (*b*) corn–soybean (CS), and (*c*) continuous alfalfa (CA).

Very poor r^2 and EF values of 0.19 and −0.26 were determined for the CA monthly predictions. A general pattern of overprediction of NO_3–N loss occurred, although peak leaching events were again underpredicted (Fig. 2). However, the overprediction of NO_3–N loss for the CA system must be considered within the context of the general magnitude of the CA NO_3–N losses, which are quite small relative to the CC and CS systems. From this perspective, EPIC clearly captured the minimal NO_3–N leaching impacts associated with CA.

Case I: Residual Nitrate Nitrogen in Soil Profile

Residual NO_3–N levels in the soil profile were measured in April and October of most years for all three cropping systems. The April soil profile residual NO_3–N amounts were generally overpredicted for CC and CS (Table 3). The mean annual residual NO_3–N amounts were overpredicted by 39% for CC, and 45 and 84% for CS when parm7 was set at 1.0 or 0.3. An opposite trend resulted for the simulated October soil profile residual NO_3–N amounts (Table 4); the average annual residual levels were underpredicted by −68% for CA, and −53 (parm7 = 1.0) and −29% (parm7 = 0.3) for CS. Setting parm7 to 0.3 for CS improved the model predictions of the soil residual NO_3–N in October due to the greater N_2 fixation simulated during the growing season. The CA residual NO_3–N amounts were accurately predicted for April 1990 and in October of 1992 and 1993, but were greatly underpredicted in October

Table 3. Observed and simulated (Case I) April soil profile residual NO_3–N for three cropping systems at Lamberton, MN.

	Residual soil NO_3–N						
	CC†		CS†			CA†	
Year	Observed	Simulated	Observed	Simulated‡	Simulated§	Observed¶	Simulated
	kg ha^{-1}						
1990	177	170	75	137	137	47	50
1991	115	206	73	158	158	ND	2
1992	86	164	61	34	108	ND	5
1993	91	111	40	30	57	ND	11
Mean (% error#)	117	163 (39)	62	90 (45)	115 (84)	–	17

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990); CA = continuous alfalfa.
‡ Simulated results with parm7 = 1.0.
§ Simulated results with parm7 = 0.3.
¶ Observed residual soil NO_3–N values were not determined in 1991–1993 (observed mean is not known).
# % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

Table 4. Observed and simulated (Case I) October soil profile residual NO_3–N for three cropping systems at Lamberton, MN.

	Residual soil NO_3–N						
	CC†		CS†			CA†	
Year	Observed	Simulated	Observed	Simulated‡	Simulated§	Observed	Simulated
	kg ha^{-1}						
1990	180	181	169	128	128	101	2
1991	94	148	63	14	67	18	2
1992	107	99	66	14	21	18	16
1993	70	50	59	12	38	28	33
Mean (% error¶)	113	120 (6)	89	42 (−53)	63 (−29)	41	13 (−68)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990); CA = continuous alfalfa.
‡ Simulated results with parm7 = 1.0.
§ Simulated results with parm7 = 0.3.
¶ % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

of 1990 and 1991. The mean annual October soil residual NO_3–N level predicted for CC was within 6% of the observed mean, and was the only predicted mean that met the criteria of 20% or less error.

Case I: Nitrogen Uptake and Crop Yield

The N uptake levels (Table 5) and crop yields (Table 6) were satisfactorily predicted for CC, CS, and CA. Errors between the simulated and observed annual N uptake means ranged between −12 and 7%. The corresponding % error range between the simulated and measured mean crop yields was 8 to 14%. The predicted N uptake was highest for CA, followed by CS, and lowest for CC, which was consistent with measured values. The extended growing season and rooting depth of alfalfa provided a greater opportunity for season-long water use and N uptake compared to row crops, which was captured by EPIC.

Case II: Tile Flow

Measurements of the complete water balance, including surface runoff, are not available for the Lamberton site. However, surface runoff has been observed to be negligible due to the almost flat slope. As stated before, it is possible that EPIC did not accurately simulate the impact of the flat slope for the row crop systems, resulting in an overprediction of surface runoff and underprediction of leached water. Thus, a CN2 calibration for CC and CS was performed for Case II, that was intended to reduce surface runoff and increase infiltration relative to the CN2 of 78 that was used for the Case I simulation. The calibration was performed on the basis

Table 5. Observed and simulated (Case I) N uptake for three cropping systems at Lamberton, MN.

	Nitrogen uptake						
	CC†		CS†			CA†	
Year	Observed	Simulated	Observed	Simulated‡	Simulated§	Observed	Simulated
	kg ha^{-1}						
1990	106	110	119	108	108	375	280
1991	136	126	227	169	175	380	270
1992	157	165	122	157	164	344	346
1993	108	141	187	145	151	272	319
Mean (% error¶)	127	136 (7)	164	145 (−12)	150 (−9)	342	304 (−12)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990); CA = continuous alfalfa.
‡ Simulated results with parm7 = 1.0.
§ Simulated results with parm7 = 0.3.
¶ % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

Table 6. Observed and simulated (Case I) crop yield for three cropping systems at Lamberton, MN.

Year	Rainfall (mm)	Crop yield CC† Observed	CC† Simulated	CS† Observed	CS† Simulated	CA† Observed	CA† Simulated
		Mg ha^{-1}					
1990	623	6.4	6.0	6.5	6.0	11.6	11.9
1991	812	7.8	7.0	2.5	2.6	11.9	11.8
1992	766	8.3	9.1	7.1	8.9	11.5	14.5
1993	1028	5.2	7.8	2.0	2.2	10.3	13.3
Mean (% error‡)	807	6.9	7.5 (8)	4.5	4.9 (9)	11.3	12.9 (14)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990); CA = continuous alfalfa.
‡ % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

of matching the predicted average annual tile flow as closely as possible to the measured mean for 1990–1993. This procedure resulted in a CN2 of 65 being selected for the Case II simulations.

Adjustments of curve numbers are appropriate to more accurately simulate management and/or cropping system practices that were not accounted for in the original curve number methodology. For example, studies by Rawls et al. (1980), Rawls and Richardson (1983), and Chung et al. (1999) showed that curve numbers needed to be reduced to reflect the impacts of conservation tillage or no-till. Curve number adjustments are also common in attempting to establish the correct field-scale or basin-scale water balances with simulation models, such as the calibration conducted by Arnold et al. (2000) with the Soil and Water Assessment Tool (SWAT) model for the Upper Mississippi River basin. However, it is recognized that the tile flow underpredictions simulated for Case I may be due in part or fully to other factors other than the CN2. Thus, the large CN2 reduction here should be viewed mainly as a site-specific experiment that cannot be extrapolated to other conditions.

Definite improvement in the predicted CC and CS annual tile flows occurred following the CN2 calibration (Table 7). Underpredictions of the 4-yr predicted mean values declined to −9 and −12% for CC and CS. The *t*-test *P* values of 0.557 and.407 for CC and CS indicated acceptance of the null hypothesis that the simulated mean of the monthly tile flows was not significantly different compared with the measured monthly tile flow mean.

Predicted Case II monthly tile flows (Fig. 3) show some increase in peak tile flows relative to Case I (Fig. 2), especially in the summer of 1993. However, the magnitude of the 1993 peak was still greatly underpredicted even after calibration of the CN2. The r^2 values of 0.88 for CC and 0.90 for CS are essentially the same as the r^2 values determined for Case I. The CN2 calibration, however, did result in improved EF values of 0.83 and 0.84 for CC and CS.

Table 7. Observed and simulated (Case II) annual tile flow for two cropping systems at Lamberton, MN.

Year	Rainfall	Tile flow CC† Observed	CC† Simulated	CS† Observed	CS† Simulated
	mm				
1990	623	20	47	19	37
1991	812	179	162	220	212
1992	766	132	153	124	127
1993	1028	443	345	480	364
Mean (% error‡)	807	193	177 (9)	211	185 (−12)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990).
‡ % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

Case II: Nitrate Nitrogen Fate and Crop Yield

The predicted CC average annual tile NO_3–N loss was identical to the measured mean (Table 8), a definite improvement compared with Case I. For CS, the simulated annual mean tile NO_3–N loss underpredicted the observed mean by −54% (Table 8), which was slightly worse than the % error determined before the CN2 calibration (Table 2). However, setting parm7 to 0.3 resulted in an error of 24% between the CS simulated and observed 4-yr tile NO_3–N loss means, an improvement from the 41% underprediction that resulted for the uncalibrated CN2 scenario. The *t*-test results were similar to those found for Case I, with acceptance of the null hypothesis for CC ($P = 0.895$) and rejection for CS ($P = 0.02$ for both parm7 simulations).

The observed and simulated trends in the monthly CC and CS tile NO_3–N losses (Fig. 4) were similar to those determined before CN2 calibration (Fig. 2). Peak leaching losses were generally slightly higher for Case II (Fig. 4), but the r^2 and EF values of 0.65 were slightly weaker than the counterpart Case I statistics. The CS r^2 and EF values were 0.56 and 0.42 with parm7 set to 1.0 and 0.65 and 0.63 when parm7 was set to 0.3. The improved results with parm7 set at 0.3 are reflected in the fact that greater leaching was predicted in all 4 yr compared with assuming a parm7 value of 1.0 (Fig. 4).

Table 8. Observed and simulated (Case II) annual tile NO_3–N loss for two cropping systems at Lamberton, MN.

Year	NO_3–N loss CC† Observed	CC† Simulated	CS† Observed	CS† Simulated‡	CS† Simulated§
	kg ha^{-1}				
1990	0	25	0	12	16
1991	70	70	81	52	74
1992	50	48	32	4	19
1993	84	62	67	15	27
Mean (% error¶)	51	51	45	21 (−54)	34 (−24)

† CC = continuous corn; CS = corn–soybean (corn was planted in 1990).
‡ Simulated results with parm7 = 1.0.
§ Simulated results with parm7 = 0.3.
¶ % Error = [(Simulated mean–Observed mean)/Observed mean] × 100.

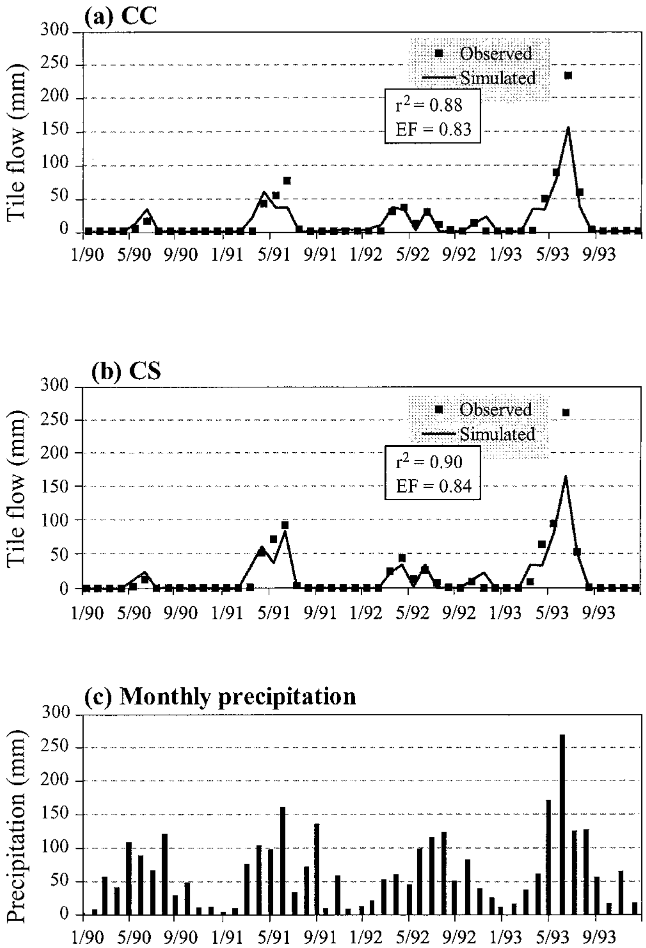

Fig. 3. Observed and Case II simulated monthly tile flows during 1990–1993 at Lamberton, MN, for (*a*) continuous corn (CC) and (*b*) corn–soybean (CS), and (*c*) monthly precipitation.

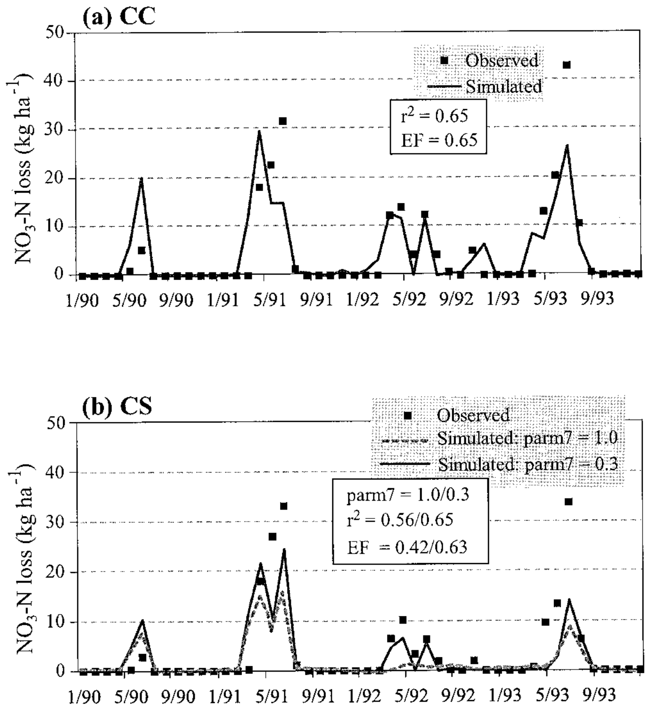

Fig. 4. Observed and Case II simulated monthly NO_3–N losses during 1990–1993 at Lamberton, MN, for (*a*) continuous corn (CC) and (*b*) corn–soybean (CS).

The April soil profile residual NO_3–N amounts were again overpredicted, with simulated means exceeding observed values by 25% for CC, and 39 (parm7 = 1.0) and 71% (parm7 = 0.3) for CS. These results represent some improvement over the corresponding Case I predictions, but still deviate greatly from the measured levels. Only slight changes in the October residual NO_3–N soil levels were predicted by EPIC following the curve number adjustment.

Essentially no change was predicted in crop yields and N uptake between the Case I and II CN2 scenarios, because the hydrologic change effect (increased or decreased infiltration) on the simulated crop yield (and thus N uptake) is not significant as long as the soil water content and soil N level are not limiting.

CONCLUSIONS

The relative impacts of the three cropping systems upon the average annual tile flows and associated NO_3–N losses were correctly predicted by EPIC under the Case I scenario. However, the average annual tile drainage flows were underestimated by >30% for CC and CS, which in turn led to an underestimation of the NO_3–N losses. Calibration of the CN2 for CC and CS (Case II) resulted in definite improvements in the average annual tile drainage flow predictions. The predicted Case II CC NO_3–N loss was almost identical to that observed; CS NO_3–N loss was only improved when parm7 was set at 0.3. Some improvement in predicted CC and CS peak monthly tile flows occurred for Case II, and also for the peak CS NO_3–N losses when parm7 was set at 0.3. However, EPIC still underpredicted the peak tile flows that occurred for CC and CS, especially in the spring and summer of 1993.

The simulation results indicate that EPIC can generally replicate the long-term impacts of CC, CS, and CA on tile flow and NO_3–N losses. The fact that improved results occurred when the parm7 and/or CN2 values were adjusted reveal uncertainty regarding the best choice of values for these inputs. The parm7 results indicate that a midpoint value of 0.5 for soybean is probably the best selection for most applications, unless further information is available to suggest otherwise.

The results of the CN2 calibration for CC and CS suggest that there could be weaknesses in the EPIC curve number methodology when simulating row crops grown on soils with relatively flat slopes. However, an overestimate of the slope at the Lamberton site could have also contributed to model error (measurement of the slope at the site should be performed before future applications of EPIC or other models). Other factors such as preferential flow may also be underlying causes of discrepancies between simulated and observed values. Extrapolation of the CN2 calibration to similar sites with level terrain would not be appropriate on the basis of this study.

The results generated with the CN2 and parm7 scenarios underscore the need for additional testing of the

EPIC modified curve number and legume N_2 fixation routines. Specifically, insight is needed to: (i) determine if the EPIC curve number approach should be further refined to better reflect expected surface runoff volumes for level or nearly level conditions, (ii) determine the optimal choice of parm7 for a wider range of conditions, and (iii) determine if the legume N_2 fixation routine and/or other portions of the EPIC N cycling submodel need to be modified to provide better results. The results of this study also underscore the need for development of an improved tile drainage routine in EPIC. Some improvements in the tile drainage routine have already been incorporated in more recent releases of EPIC (J.R. Williams, personal communication, 2000, Texas Agric. Exp. Stn., Blacklands Res. Lab., Temple, TX). Future research efforts on simulating tile flow and tile NO_3–N loss with EPIC will be performed with this updated methodology.

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